Sustainable Solutions for Internal Mobility in Spread University Campuses

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Abstract: - The 95% of the energy employed is derived from fossil fuels and the transportation sector is responsible for significant part of the air pollution since it is mainly based on the use of diesel engine. In order to cope with these facts, the European Commission proposed a roadmap towards a more resource efficient and competitive transport system. Moving towards a sustainable mobility model is a complex task that involves both technological and social aspects. It is important that the dissemination of these new concepts and new ways of thinking about mobility, the so-called Smart Mobility, starts from Institutions, such as the university campuses. For this reason, this work presents an idea to realize a sustainable University Campus spread in downtown and suburban areas, promoting the use of different kinds of Electric Vehicles (EVs), in particular, E-bike, E-car, E-van, light electric quadricycle and medium-duty E-truck. These EVs are charged through the Renewable Energy Source (RES), in particular, solar energy available in the Campus and they have to be seen as a reinforcement of the public transport system. The characteristic of this project is that the same solutions can be in general applied to any spread campus.

Key-Words: - Petri net; electric vehicles; sustainable campus; E-mobility; green energy.

1 Introduction

Different actions to reduce GreenHouse Gas (GHG) emissions have been discussed in the Twenty-First Conference of the Parties - COP21 and a particular attention has been paid to the transport sector [1].

The consideration to this sector in terms of climate change, the rise of fuel prices as well as the technological innovations on battery technology, have convinced several car manufacturers worldwide [2] in investing in new vehicle models powered by batteries, recognized as Electric Vehicles (EVs).

EVs contribute to lower the GHG emissions as they do not produce local exhausts as opposed to Internal Combustion Engine (ICE) vehicles [3]. However, the emissions levels by EVs vary depending on how the electricity is produced. If the generation is based on coal power plants, the benefits of using EVs are only local, because the emissions are shifted to the location of the production plant [4]. If the electricity is produced by less carbon-intensive energy sources, such as wind power and photovoltaic (PV), GHG emissions are significantly lower. However, it is found that even with coal-generated electricity, GHG emissions are lower for EVs than ICE vehicles.

National and local authorities in different countries [5] have started to provide support for the introduction of EVs, granting them special treatments in comparison to conventional cars, with measures like tax incentives, reduced tariffs in parking lots, free access to restricted traffic areas, the use of bus lanes, and etc. [6].

However, a big challenge is to reduce the charging time in order to let EV competing with ICE vehicles. Fast charging technology, that allows to recharge a fully depleted 24 kWh battery up to 80% of its capacity in 30 minutes, has been developed to decrease the charging time, though it is currently possible on few vehicle models. Moreover, fast charging needs fast charging station [7] that are quite expensive and can impact the battery lifetime negatively if used on a daily basis [8].

With regard to vehicle costs, consumers worldwide tend to focus on initial costs, rather than on operating costs, when making purchasing decisions [9]. The purchase cost of an EV is about 30-40% higher than an ICE vehicle [10], while the running costs of an EV can be quite lower. The cost of charging depends on the electricity price, which may vary according to the country. Currently, in European countries as well as in the U.S., the cost per km driven by an EV is about one-fifth of the cost per km driven with an ICE city car [11 - 14].

With regard to EV integration in electric grids, the electric demand due to EV charging is still negligible today. With a widespread adoption of EVs, the additional electric demand can have proportions that affect the operation of the electric power system, in a positive or negative manner. In fact, if the charging of EVs is unconstrained, the additional demand during peak electricity hours can challenge the operation of the power system and underutilize the energy produced by Renewable Energy Sources - RES. As a consequence, the unconstrained charging can lead to extra investments in generation and transmission capacity, to increased ageing of the distribution components and to power quality issues [15].

On the contrary, if the charging of EVs is supported by more intelligent charging schemes that take into account the actual production of RES, both the environmental value and the value created for the electric energy sector may result increased [16 - 18].

For this reason, the Smart Mobility term is a new way of thinking about mobility and it is important that the application of this concept starts from the public institutions, for example the universities [19], [20] that can play a key role in disseminating these new ideas to the people . This is the reason why this work is related to a university campus scattered inside and outside the downtown and characterized by an efficient public transportation system [21], [22].

The aim of this study is to present a project for a sustainable University Campus, where different kinds of electric vehicles, in particular e-bike, e-car, e-van, light electric quadricycle and medium duty e-truck are used for those services that cannot be executed by the public transport system. These EVs are mainly charged through renewable energy sources with particular focus on the solar energy available in the Campus.

The paper is structured as follows. Section 2 is an overview about smart mobility and electric vehicles. In Section 3, the Bovisa Campus and its photovoltaic electricity potential are described. The Section 4 presents the Petri net for the case study. The discussion of results is reported in Section 5 and Section 6 draws the conclusions.

2 Smart Mobility and Electric Vehicles

From the mobility point of view, switching to a Smart Campus means reducing the number of vehicles, thus emissions, traffic and physical footprint, (i.e. due to car parks), finding an alternative to the predominant use of private cars and to conventionally fueled vehicles.

A first step is a change, already underway, in the mobility paradigm that is the transition from an ownership to a sharing logic. In fact, to move from a place to another, it is not always necessary to own a vehicle but it can be enough to take advantage of a certain service. This can be provided by public transport, a car (or bike) sharing, ride sharing or car pooling system. In order to have a better understanding of the different possibilities, it is helpful to point out the differences between car sharing, car pooling and ride sharing, following the classification made in [23] [24].

We refer to car sharing when different people use the same vehicle in different moments for the desired trips, normally short-distance ones. Car pooling consists of the sharing of a vehicle by a group of users, generally fixed, in order to travel for an established route, for example home-workplace, at given hours in the day. Ride sharing category distinguishes itself due to the presence of a driver: people use the same vehicle in different times for different trips but a driver is always present.

Besides the transition to a sharing attitude, it is also fundamental to find an alternative to traditionally fueled vehicles such as gasoline and diesel fueled cars. The available options present some issues related to autonomy, availability of infrastructures and charging strategies. This work considers EVs as the future solution, even if currently their diffusion is still limited.

EV presents the great advantage of being emission-free in the use phase. Nevertheless, the electricity required by the motor can be produced in several ways and, as formerly said, EV is actually emissions-free only if this energy is derived from Renewable Sources [26], [26].

Anyway, the interaction between EV and the electrical network is the real value added of this technology, which makes it more promising than the aforementioned solutions [27]. In effect, EV can be seen as a four-wheeled battery, thus it can be exploited as a form of energy storage and as a support to the grid. For example, the EV can be charged during the night or in moments where the demand is low in order not to increase the requested peak power while, during peak hours, it can provide energy to the grid, according to a Vehicle To Grid (V2G) strategy [28]. Another possibility is that of using EVs to absorb excess power produced by RES which otherwise would cause unbalances and congestions on the grid [29]. Therefore, thanks to optimal charging strategies, the EV can be

integrated with the electrical network in a Smart Grid perspective, increasing its flexibility and contributing to the management of Distributed Generation [30], [31].
Table 1 reports the vehicle fleet chosen to achieve these goals includes e-Bikes (B_i), light electric quadricycles (Q_i), e-Car (C), e-Vans medium duty (V_i) and e-truck (T) indicating different information regarding these vehicles.

Table 1 Different Typologies and Characteristics of Electric Vehicles

		Number of available EVs	Battery Capacity [kWh]	Driving Range [km]	Energy consumption [Wh/km]
B_i		50	0.4	40	10
Q_i		10	6	80	86
C		1	80	200	120
V_i		3	24	160	150
T		1	55	200	360

3 Case study: The Milano Bovisa Campus

The Milano Bovisa Campus arises on the ancient industrial area of Bovisa located in the northeast part of Milan outside the downtown (Fig. 1) [32].
The campus has been substantially expanded as the result of an international competition, which was announced in 1998 by Politecnico di Milano in collaboration with other local entities (Municipality and Region) and which has brought about a general renewal of the zone. The Milano Bovisa campus is easy to reach as it is placed in between two railway stations.
The location of Bovisa campus is strategic as it can be reached easily using public transport from and towards surrounding cities, Milan downtown, Central Railway Station, Malpensa International Airport and most places of interest.
However, there is a lack of access to the local road system that makes private mobility difficult as well as reaching of other locations that belong to other campuses of the university. In this study the focus is to integrate two factors in particular transportation and electricity obtained from RES.

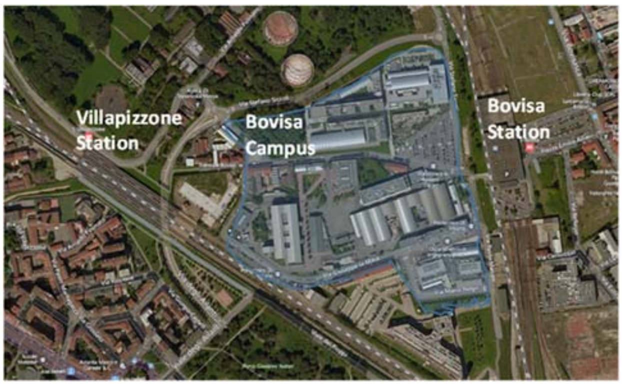


Fig. 1. View of the Bovisa Campus.

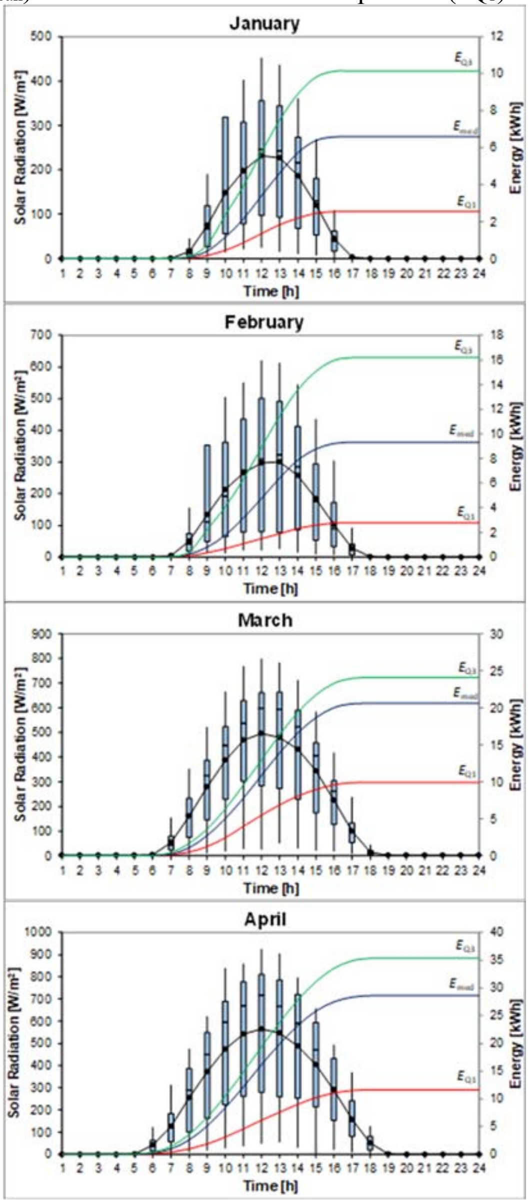
Environmental and PV production data of the Campus are available thank to the SolarTech Lab, founded at Politecnico di Milano in 2012 [24]. SolarTech Lab, located at a latitude of 45.502941°N and a longitude of 9.156577°E, presents different technologies: Si-polycrystalline, Si-monocrystalline, PV-thermal and Si-amorphous modules. Most of the PV modules face south with a tilt angle from 15° to 30°, except two of them which have tunable tilt angle. PV modules are connected to the low-voltage distribution grid through commercial microinverters so that the operating conditions of every module can be optimized. Some of these modules are fixed and unchanged since 2012, some others are instead usually changed due to experimental and research activities.

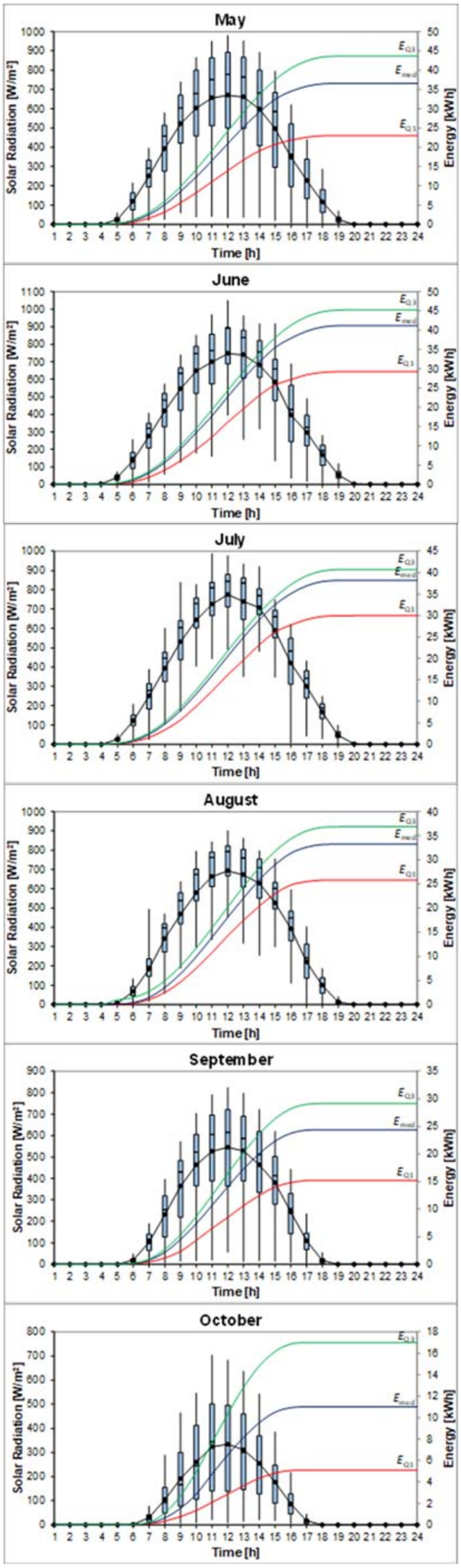
Solar irradiance, air temperature, humidity, and wind have been continuously measured by a meteorological station. Solar irradiance is measured by three different sensors: a net radiometer measuring the Direct Normal Irradiance (DNI) and two pyranometers that measure the global on horizontal plane and diffuse irradiance. More information regarding the PV characteristics and the meteorological station of Solar Tech Lab are presented in [28] [29]. Fig. 2 shows the view of the PV modules installed at the SolarTechLab.

Fig. 2. View of Solar Tech Lab.

The data collected during 2012-2015 on the global irradiance on horizontal plane have been processed using Minitab software in order to estimate the electricity production of a photovoltaic system at the service of the campus. They have been characterized using the box plot graph. The use of this graph is useful to calculate the average energy available during the month, the most probable variation range and the maximum and the minimum production that can occur. However, the outlier data have not been represented, but considered in the statistical analysis. Fig. 3 shows for each month the hourly quantities have been represented with their boxplot, moreover the energy production have been represented on the same plots.

In particular, the Green Line represents the upper quartile (E_{Q3}), the Blue Line identifies the median (E_{mean}) and the Red Line is lower quartile (E_{Q1}).





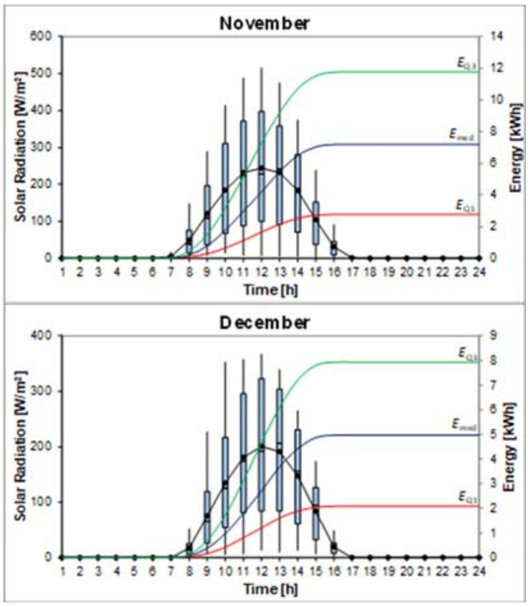


Fig. 3. Monthly solar radiation and Energy in Bovisa campus area during 2012 - 2015.

4 Smart Campus Mobility Model using Petri Net

In general, a Petri Net is defined as a particular directed graph consisting of places, transitions, input arcs and output arcs. Input arcs link a place to a transition, conversely output arcs connect a transition to a place. Each arc can be weighted with a positive value. The state of the place is defined by the number of tokens, the marking, that it contains. A transition consists in an activity that can be fired only if it is enabled, i.e. there are enough tokens available in the input places of the transition. Once the transition is fired some tokens will be moved from input to output places, depending on the weight of the arc connecting the transition with the corresponding place. Usually, places are represented by circles, transitions by bars and tokens by dots.
A Petri Net is represented through the following relations:

$$
\begin{gathered}
PN = \{P, T, Pre, Inhib, M_0\} \\
P = \{p_1, p_2, \dots, p_n\} \\
T = \{t_1, t_2, \dots, t_m\} \\
Pre = Post = Inhib = \{P \times T\} \rightarrow N
\end{gathered}
\tag{1}
$$

In witch P is a finite and non-empty set of places; T is a finite and non-empty set of transitions. The terms *Pre* is an input function and *Post* is an output function that defines respectively the directed weighted arcs from places to transitions and viceversa. *Inhib* is an inhibitor function which defines inhibitor weighted arcs (circle-headed weighted arcs) from places to transitions where N is a set of nonnegative integers. M_0 is called initial marking (initial distribution of the tokens in the places). A place P connected with a transition by an arc can be defined as input, output or inhibitor in relation to the type of the arc [26].

The transportation system has been modelled through the Petri Net in order to find the best path that optimizes the use of available renewable energy on the campus.
In this case, a Petri Net with N places indicated with $S = \{S_1, S_2, \dots, S_N\}$ has been considered. These places represent different points of interest that can be reached using electric vehicles started from Bovisa Campus, as shown in Fig. 4. In this system, only the Bovisa place indicated with S_A is equipped with the charging system that provides the energy to the electric vehicles for their journeys. For this reason, all vehicles must came back to the Bovisa Campus for their recharge.

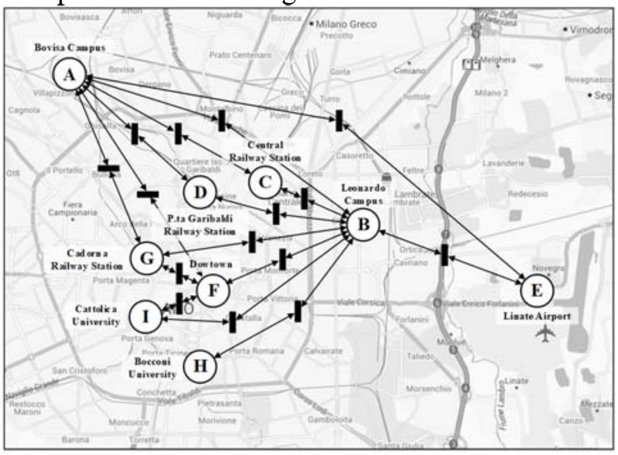


Fig. 4. Different points of interest.

Table 2 represents the distance of the various places of interest from Bovisa Campus and the average travelling time.

Table 2 Distances and travelling times for different trips

Places (from)	Places (to)	Distance [km]	Time [min]
Bovisa Campus (A)	Leonardo Campus (B)	9	28
Bovisa Campus (A)	Downtown (F)	8	26
Bovisa Campus(A)	Central Railway Station (C)	7	22
Bovisa Campus (A)	Garibaldi Railway Station (D)	6.1	16
Bovisa	Linate Airport (E)	30.5	31

Campus (A)			
Bovisa Campus (A)	Cadorna Railway Station	6.7	20
Leonardo Campus (B)	Central Railway Station (C)	2.3	12
Leonardo Campus (B)	Garibaldi Railway Station (D)	3.7	10
Leonardo Campus (B)	Linate Airport (E)	5.7	13
Leonardo Campus (B)	Downtown (F)	3.8	17
Leonardo Campus (B)	Cattolica University (I)	6.5	28
Leonardo Campus (B)	Bocconi University (H)	5.8	19
Leonardo Campus (B)	Cadorna Railway Station (G)	6.2	20
Cattolica University (I)	Downtown (F)	1.6	8
Downtown (F)	Cadorna Railway Station (G)	1.7	8

5 Results and Discussion

All the locations listed in Table 2 can be easily reached with one of the vehicles (see Table 1). Different scenarios for each category of EVs have been taken into account.

Electric car is available for professors as official car and it can reach all the locations identified in Fig. 4. The vehicle can travel on three typical paths in a day, according to the mobility needs of the teaching staff. These routes have been optimized in order to reach as many places as possible with the lowest energy usage. The first path, 30.8 km long and hereafter indicated with C.1, starts from Bovisa Campus (A), passes through P.ta Garibaldi Railway Station (D), Leonardo Campus (B), Downtown (F) and Cadorna Railway Station (G), then comes back passing through Leonardo Campus (B), Central Railway Station (C) and its end in Bovisa Campus (A). The second path, 42.2 km long and hereafter indicated with C.2, is obtained from C.1 adding a round trip from Leonardo Campus (B) to Linate airport (E). The third path, 57.7 km long and hereafter indicated with C.3, is the same of C.1 up to the second passage in Leonardo Campus, and then it goes to Linate airport (E) and comes back to Bovisa Campus (A) through expressway. The places, transitions, input arcs and output arcs of the Petri network involved in these paths are highlighted in the left part of Fig. 5a.

Electric bikes are available for students and professors. In this case, it has been assumed that the e-bikes are mostly used to move between railway stations and Bovisa Campus (A). B.1 indicates the 14 km long round trip to Central Railway Station (C), B.2 is the 12.2 km long round trip to Garibaldi Railway Station (D) and B.3 is 13.4 km long round trip to Cadorna Railway Station (G). The places, transitions, input arcs and output arcs of the Petri network involved in these paths are highlighted in the left part of Fig. 5b.

Light electric quadricycle are available for professors and other university employees for their mobility inside the various campuses. They are mainly used to reach the railway stations, downtown and Leonardo Campus. As for the electric car, four typical and optimized paths have been defined, according to the mobility needs of the teaching and technical staff. The first path, 21.2 km long and hereafter indicated with Q.1, starts from Bovisa Campus (A), passes through Cadorna Railway Station (G), Downtown (F), Leonardo Campus (B) and comes back to Bovisa Campus (A). The second path, 21.1 km long and hereafter indicated with Q.2, starts from Bovisa Campus (A), passes through Central Railway Station (C), Leonardo Campus (B), Downtown (F) and comes back to Bovisa Campus (A). The third path, 21.6 km long and hereafter indicated with Q.3, differs from Q.2 only for the railway station that is reached, which is P.ta Garibaldi (D) instead of the Central station (C). The last path, 22.2 km long and hereafter indicated with Q.4, starts from Bovisa Campus (A), passes through Cadorna Railway Station (G), Leonardo Campus (B), Central Railway Station (C) and comes back to Bovisa Campus (A). The places, transitions, input arcs and output arcs of the Petri network involved in these paths are highlighted in the left part of Fig. 5c.

Electric Vans are available in passenger or van configuration for the three Departments (Energy, Mechanic and Management) inside the Bovisa campus. The e-Vans usually travel between university locations. It is also possible to use these vehicles to transport passengers from/to Linate Airport. Five typical paths have been defined for this kind of vehicles. The first one, 18 km long and hereafter indicated with V.1, is a round trip to Leonardo Campus (B). The second path, 31 km long and hereafter indicated with V.2, is a round trip to Cattolica University (I) passing through Leonardo Campus (B). The third path, 29.6 km long and hereafter indicated with V.3, is a round trip to Bocconi University (I) passing through Leonardo

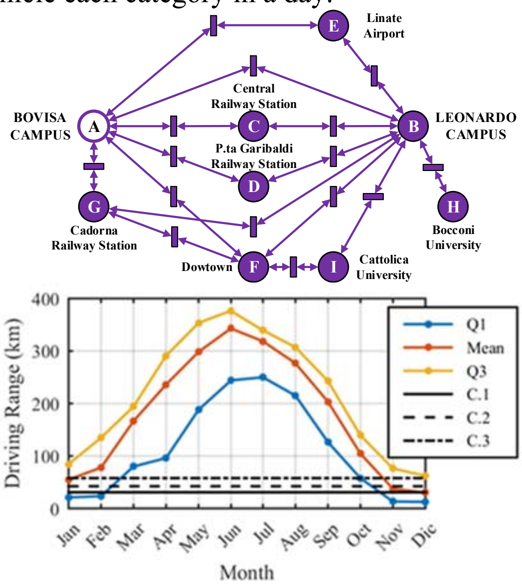
Campus (B). The forth path, 61 km long and hereafter indicated with V.4, is a round trip to Linate Airport (E). The last path, 45.2 km long and hereafter indicated with V.5, is a ring passing through Leonardo Campus (B) and Linate Airport (E). The places, transitions, input arcs and output arcs of the Petri network involved in these paths are highlighted in the left part of Fig. 5d.

Electric truck is available for all Bovisa campus. It has been assumed that the e-Truck is mainly used to transport heavy goods as machineries, laboratory devices and instrumentations, etc. between university locations, as e-Vans. The three paths that have been considered for the e-truck, hereafter indicated with T.1, T.2 and T.3, are the first three paths identified for the e Van; V.1, V.2 and V.3 respectively. The places, transitions, input arcs and output arcs of the Petri network involved in these paths are highlighted in the left part of Fig. 5e.

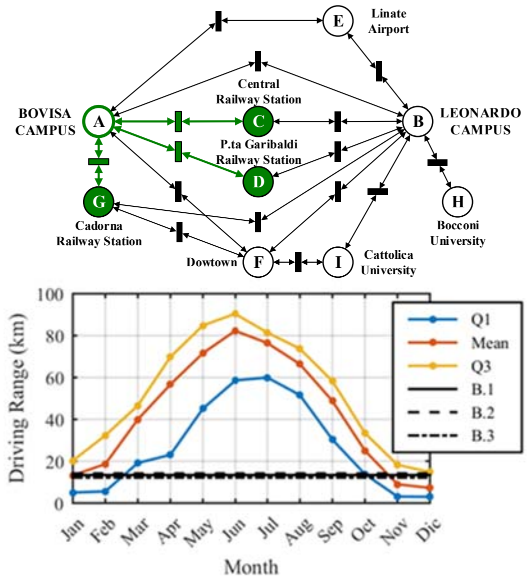
In order to estimate how many journeys a fleet of specific vehicles can travel, it has been assumed that all the green energy produced by the Solar Tech Lab is used for the vehicles charging. Five scenarios have been defined: each one considers charging a single fleet of electric vehicles (see Table 1) at a time.

This analysis has been carried out taking into account not only the average value of the energy production (E_{mean}), but also the first (E_{Q1}) and the third quartile (E_{Q3}). In this way, it is possible to have an estimation of the travel distance with green energy in the best and in the worst cases.

The results of this analysis are shown in the right side of Fig. 5, where the driving distance for a vehicle of each category described in Section 2 is reported and compared with the distance traveled by a vehicle each category in a day.



(a)



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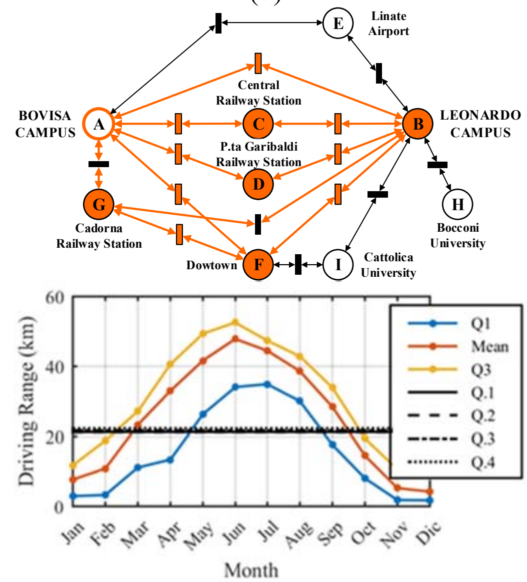

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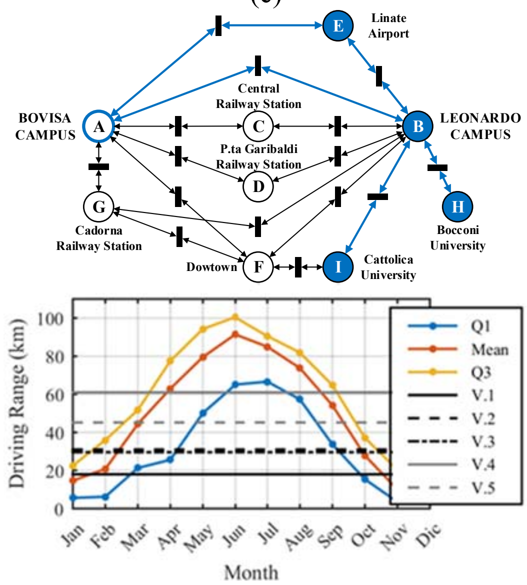

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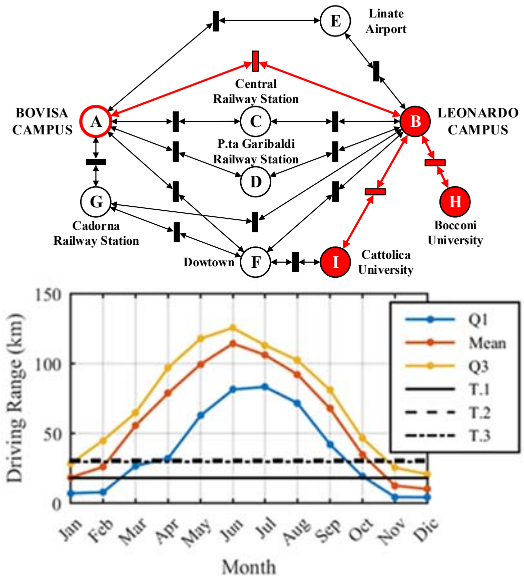

(e)

Fig. 5. Locations used for the simulation.

The first case here discussed is the recharge of the e-car with the energy produced by the PV plant. The right side of Fig.5a shows the driving range and the length of paths considered for the e car. In the sunny days of winter months, the energy produced by the PV plant is enough to let the e-car travel one trip on one of the three paths, while in the cloudy days it does not allow to travel a full trip. Instead, in the other months the green energy available allows the e car traveling for more than one trip a day. In the summer months, the mean energy produced is form 5 to 7 times the energy needed for a trip, thus a part of the energy produced by the PV plant could be used for the recharge of other vehicles, such as e-bikes.

The second case analyzes the recharge of the fleet of e-bikes with the energy produced by the PV plant. The right side of Fig.5b shows the riding range and the length of paths considered for one e bike of the fleet. The results are quite similar to the case of e car: only in the cloudy days of winter the green energy produced by the PV plant is not enough to let the whole fleet of e-bikes to take a round trip from the Campus to the railway stations. In this case, only a part of the e-bike fleet is available to travel the paths defined for this vehicle. On the other hand, during summer, the energy produced by the PV plant could be used for the recharge of more e-bikes and/or other vehicles.

The third case analyzes the recharge of the fleet of light e-quadricycles with the energy produced by the PV plant. The right side of Fig.5c shows the driving range and the length of paths considered for one light e-quadricycle of the fleet. This case is worse than the cases previously analyzed: the energy produced by the PV plant is not enough to recharge the entire fleet during 5 months, from October to February, even in the sunny days. Only in the months of June and July, the whole fleet can take, on average, two trips a day along a path.

The right side of Fig.5d shows the driving range and the length of paths considered for one e-van of the fleet. In this case, the results obtained are heterogeneous and strongly depend on the route traveled by e vans. The results obtained for the short city paths (V.1, V.2, V.3) are similar to the cases of light e quadricycle. On the other hand, long paths on expressway require a great amount of energy that can be produced by the PV plant only in the summer.

The latter analysis takes into account the e-truck. The right side of Fig.5e shows the driving range and the length of paths considered for the e truck. The results obtained are halfway between the e-car and the short city paths of e-van. The truck has a consumption per kilometer larger than the car, however the typical paths for this vehicle are shorter than those of the car. Consequently, the daily energy demand of the truck and car is similar.

5 Conclusion

This paper proposes some scenarios for the enhancement of sustainable mobility system in university campuses, applying them to the Bovisa Campus of Politecnico di Milano. The reinforcement of the mobility system is based on different types of EVs that use for their recharge the green energy produced by the PV plant already installed in the campus, at the SolarTechLab on the roof of the Department of Energy. The radiation and the photovoltaic electricity production measured during one year survey have been elaborated with a statistical tool to consider the natural variability that characterizes renewable sources.

Five categories of electric vehicles useful to integrate the public transport from and to Bovisa Campus have been selected, defining five uniform fleets of vehicles. The driving range for each vehicle of each fleet has been estimated assuming that the electric energy produced by the PV plant is entirely used for the batteries charging of one fleet at a time. During winter months, and especially in cloudy days, the available green energy is not enough to ensure, at least, one trip to each vehicle of each fleets. The same condition also occurs in some spring and autumn months, with regard to fleets of e bikes and e-van. On the contrary, in the summer the driving range is always higher than the mean travelled distance for each fleet of vehicles. In these months, the excess of energy could be used for charging other types of EVs, or to allow the vehicles of the same fleet to travel on the same path more than once a day.

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